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OPTICAL PUMPING OF THE POLARIZED H$^-$ ION SOURCE AT LAMPF

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Abstract

We report experiments to understand the laser optical pumping efficiency for the Optically Pumped Polarised Ion Source (OPPIS) at LAMPF. We have measured ion beam polarisation and current vs. laser power and potassium vapor thickness in order to understand the dependence of source performance on laser power and other parameters. Attempts to fit the data with simple scaling models to evaluate projected performance improvements are shown. Development of economical ways to make more efficient use of available laser power are described.

1 Introduction

The H$^-$ current from OPPIS [1] is an increasing function of the optical pumping target thickness. However, thicker targets require more laser power to achieve the same degree of polarisation. Thus, optimising source performance (in terms of some figure of merit combining current and polarisation) requires determining the optimum thickness for the available laser power, or stated differently, determining the laser power necessary to reach some performance level. Section 2 shows measurements from the LAMPF OPPIS addressing these issues.

The target polarisation is determined by equilibrium between the rate of polarisation by optical pumping, and the rate of depolarisation by wall collisions. These factors alone give a simple model of optical pumping which can be useful for understanding qualitative features of the measurements; this is discussed in Section 3. Section 4 describes modifications of our Ti:sapphire laser system to realise the benefits of higher laser power.

2 Nuclear polarization vs. laser power and target thickness

For high-duty-factor sources, available laser power is critical to source performance. Fig. 1 shows H$^-$ nuclear polarisation, measured at the 800-MeV polarimeter, as a function of laser power for different target temperatures. Data for laser powers less than 5 W was taken with one laser and a variable attenuator, while powers greater than 5 W were obtained with two lasers. The laser powers quoted were measured in the laser lab before the beam was transported to the cell; we estimate that 75±10% of the laser light reaches the cell. Although laser powers above 4 W afford only a modest gain in polarisation, a thicker target can be polarised; the H$^-$ current increases 30% by changing the target temperature from 141°C to 150°C.

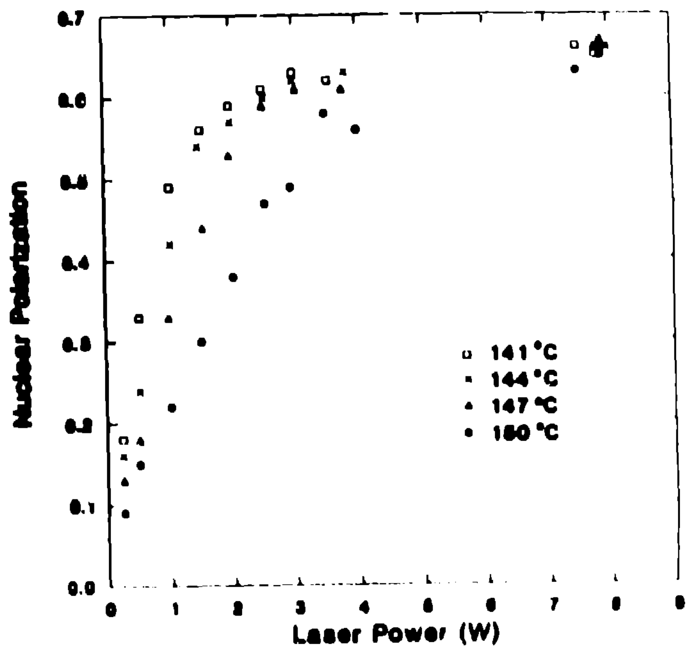

Figure 1: Nuclear polarisation vs. laser power.

At laser power above 4 W, it appears that the H$^-$ polarisation saturates with limiting value near 70%. However, it is not conclusively known that the corresponding values of vapor polarisation are near 100% because of the questions of spectral overlap with the Doppler-broadened K absorption profile and spatial overlap of the laser beam with that portion of the vapor which contributes to the final ion beam. Exploration of these questions will be facilitated by two-laser operation this year.

Fig. 2 shows data for optimising target thickness when polarised by one 4-W laser. The beam polarisation and current were measured for different target temperatures. The quoted target thicknesses are accurate to ±20% and were determined from the temperature using a vapor pressure curve and a fit to Faraday rotation measurements. The H^- beam currents were measured at 750 keV and were limited to less than our typical values (25 μA peak at 5×10^{13} cm^{-2}) because all parameters were not optimised. The current measurements above 5×10^{13} cm^2 show an anomalous laser-induced effect [2] and are not included. The maximum polarisation was obtained for thicknesses less than 4.0×10^{13} cm^{-2} (<137°C) while the best P^2I was achieved at approximately 5×10^{13} cm^{-2} (140°C). In subsequent experiments, finer adjustments of the laser allowed us to achieve 57% polarisation at 5.3×10^{13} (141°C). It should be noted that the measurements in Fig. 2 were made using a 7-mm-diameter ion beam and a 10-cm-long vapor cell, while those of Fig. 1 were with a 5-mm beam and a 16-cm cell. The higher polarisation shown in the earlier figures is related to the smaller ion beam size as explained in the companion paper [3].

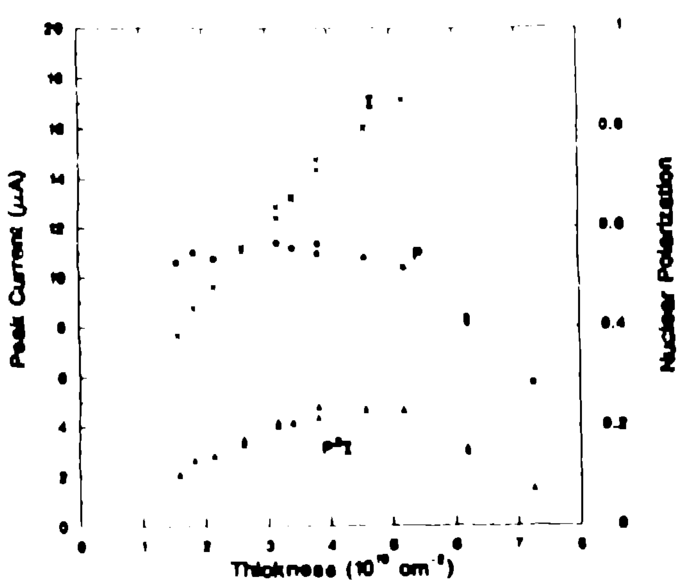

Figure 2: Nuclear polarisation P, current I, and P^2I vs. target thickness.

3 Two level optical pumping model

The saturation of polarisation in the optical pumping of thick alkali vapors can be illustrated with a simple two-level model [4] which yields analytical equations that can be fit to the data. Briefly, two rate equations describe the evolution of the populations of the two spin-orientation states of the ground level of the atom under the process of optical pumping and wall relaxation. Solving these equations for steady-state conditions gives expressions which relate the average vapor polarisation to the incident and transmitted laser power:

$$\frac{I_O - I_L}{I_S} + \log\left(\frac{I_O}{I_L}\right) = \frac{\sigma_e \rho L}{2} \qquad (1)$$

$$P_N = \alpha \bar{P} = \frac{2\alpha}{\sigma_e \rho L I_S}(I_O - I_L) \qquad (2)$$

$$I_S = \frac{3A\lambda\nu}{\sigma_e \tau} \qquad (3)$$

where I_0 is the incident laser power, I_L is the laser power after passing through the vapor, I_s is the "saturation power," ρL is the thickness of the vapor, σ_e is the effective cross section for laser absorption, P_N is the H^- nuclear polarization, α is the polarisation transfer efficiency, $\bar{P}$ is the average polarisation in the vapor, **A** is the area of the beam, and τ is the relaxation time of the polarisation.

Fig. 3 shows a fit of the polarisation and laser transmission data from Fig. 1 at 141°C to the two-level model of the optical pumping. For these data the fit is quite good. The values for the fit are I_S= 170 mW, $\sigma_e\rho L/2$ = 8.8 and α = 0.67. Fitting the data for the higher target temperatures gave erratic results and it is not clear whether the problem was in the accuracy of the data or a breakdown in the assumptions of the model; this remains to be explored further.

4 Spin flip with two lasers

To realise the benefits of higher laser power, we are developing a system to use both lasers to pump both spin states.

In 1990 we used one laser (Spectra-Physics 3900) per spin state. In order to use both lasers for each spin

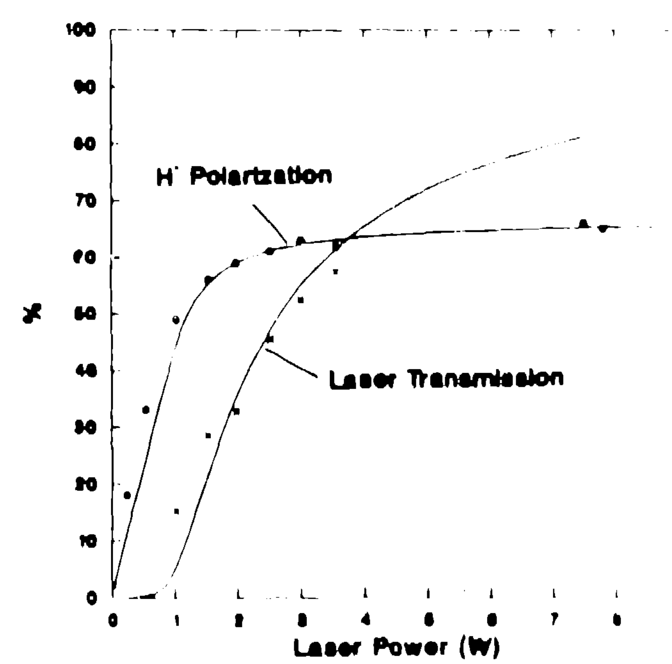

Figure 3: H⁻ polarisation and laser transmission vs. laser power.

state, is necessary to change the helicity of the laser beams from σ^+ to σ^- and tune laser frequencies to both σ^+ and σ^- transitions. The transitions are separated by 2.00 cm^{-1} in the 16-kG magnetic field of the polariser cell.

The frequency of the lasers is determined by their tuning elements. Each laser has a birefringent filter (BRF), a thin etalon with a 7-cm^{-1} free spectral range (FSR), and a temperature-stabilised thick etalon with a 0.67 cm^{-1} FSR. The etalon stack is chosen to reduce the laser bandwidth to about 500 MHz to better match the K-absorption linewidth. Tilting or changing the temperature of the thick etalon gives essentially continuous tuning in a 0.67-cm^{-1} range. Tilting the thin etalon causes the frequency to jump in quanta of 0.67 cm^{-1}, one thick etalon mode. Thus, tuning the lasers from σ^+ to σ^- requires tilting the thin etalon to hop three thick-etalon modes, or 2.00 cm^{-1}.

The micrometer positioners for the BRF and thin etalon have been replaced with computer-controlled stepping-motor micrometers (Oriel models 18500 and 18512). When a spin flip is desired, the micrometers move the approximate distance to hop three thick-etalon modes. A feedback loop then peaks the laser power with the BRF and thin etalon. The frequency of the laser is confirmed with a wavemeter and corrected if necessary. The final system will flip spin in under 10s.

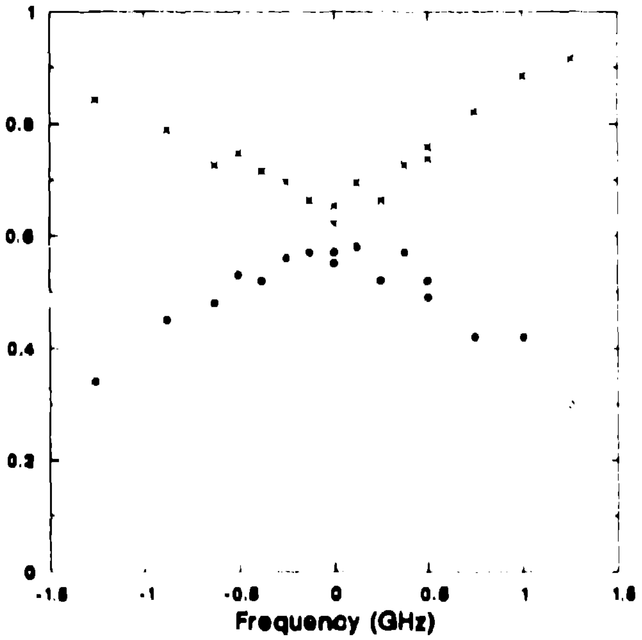

Figure 4: H$^-$ polarisation (circles) as a function of pump-laser detuning from K line center. The polarisation remains high for detunings within $\pm$ 0.01 cm^{-1} ($\pm$300 MHz). The transmission of the laser beam through the target (crosses) is an operationally useful relative indication of polarisation.

The temperature-controlled stabilisation of the thick etalons limits the frequency drift to within $\pm$ 0.01 cm^{-1}; this drift has minimal effect on polarisation as illustrated in Fig. 4. For this method to succeed, the FSR of the thick etalons in the two lasers must be closely matched to each other and to the σ^+/σ^- splitting determined by the magnetic field. Our two etalons have a frequency change of 1.980 and 1.965 cm^{-1} per three mode hops. The superconducting magnet has been adjusted slightly to give a 1.97 cm^{-1} splitting between the σ^+ and σ^- transitions in K.

The two laser beams are combined with little power loss and with parallel polarisations by using a sharp-edged mirror. The beams are about 3 mm apart at the mirror and essentially overlapping when they reach the source 8 m away. A Pockels cell (Quantum Technology QK-24) transforms the linearly polarised beams into σ^+ or σ^- helicity, depending upon the applied voltage.

References

[1] R. L. York, in *Proceedings of the International Workshop on Polarized Ion Sources and Polarized Gas Jets*, edited by Y. Mori (KEK, Tsukuba, Japan, 1990), p. 142.

[2] A. N. Zelenskii, et al. (above proceedings) p. 154.

[3] R. L. York et al., Operation of the Optically Pumped Polarised H$^-$ Ion Source at LAMPF, in *Proceedings of the IEEE Particle Accelerator Conference* (to be published).

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